

The
DOMINION
ASTROPHYSICAL
OBSERVATORY
VICTORIA B.C.

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Frontispiece—BUILDING AND DOME FROM SOUTH

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The
Dominion Astrophysical
Observatory
Victoria, B.C.

A SKETCH of the development of astronomy in Canada and of the founding of this observatory. A description of the building and of the mechanical and optical details of the telescope. An account of the principal work of the institution.

By
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THE DOMINION ASTROPHYSICAL OBSERVATORY

VICTORIA, B.C.

By J. S. PLASKETT, Director.

SECTION I.—HISTORY AND CONSTRUCTION

Introduction

This description of the observatory, its equipment and work has been written by the director in response to a need, frequently expressed by the numerous visitors to the institution, of a non-technical account of the principles of the telescope and of the work of the institution. This account will commence by a short historical sketch of the beginnings of the undertaking followed by a description of the observatory and telescope and concluded by a resume of its work.

Historical Sketch

This observatory is a branch of the Department of the Interior of the Federal Government, the department which has charge of the administration of the western lands of the Dominion. In the colonization of these lands, one of the obvious first needs was a survey of the boundaries and subdivision into townships and sections. This need led to the organization of a surveys branch of the department and out of the necessity of accurate astronomical observations to delimit the boundaries and define the position of the base lines for subdivision work arose the astronomical branch. The first Chief Astronomer of Canada, the late Dr. W. F. King, was a man of sterling integrity and remarkable ability and to his genius must be ascribed in large degree the present development of astronomy in Canada. As Chief Astronomer and H. M. Commissioner of International Boundaries, he

early realized the need of an observatory for an initial meridian, for housing and standardizing the instruments, and for some astronomical research. He was successful in having the fine Dominion Observatory erected on the Experimental Farm, Ottawa, in 1905 which housed the Astronomical Branch, the staff of the International Boundary Surveys and later the Geodetic Survey of Canada, of which he was the first superintendent.

The Dominion Observatory was equipped with a 15-inch refractor provided with micrometer, photometer, solar and stellar cameras, and spectrograph. The writer was entrusted with the work with this telescope and the spectroscopic work especially was energetically developed and helped, with the other activities of the institution, to bring gratifying recognition from the scientific world. The need of a larger aperture for extending this part of the work was soon realized by the writer and was brought to the attention of the Government. After some delays, owing to various circumstances, it was finally decided early in 1913 to provide a large reflector for extending the work. Enquiries were at once made, specifications prepared and estimates obtained from prospective makers of the instrument. Contracts were finally awarded in October 1913 to the John A. Brashear Co. of Pittsburgh for the optical parts and to the Warner & Swasey Co. of Cleveland for the mechanical parts of a 72-inch reflecting telescope.

Location

It was necessary to know the location of the instrument before the design of the mounting could be completed as the angle of the polar axis depends upon the latitude of the site. When the new telescope was first proposed there was no thought of locating elsewhere than at the seat of government at Ottawa. However, upon further consideration it was decided that the telescope should be located where, in Canada, the best observing conditions prevailed. To determine this location preliminary selection of five likely stations was made by the aid of Sir Frederic Stupart, chief of the Meteorological Service from the meteorological records.

These stations, at Ottawa, at Medicine Hat, at Banff, at Penticton, and at Victoria were occupied by Mr. W. E. Harper, astronomer at Ottawa and the astronomical conditions were observed by means of a 4.5-inch telescope. Victoria was unmistakably superior in "seeing" or defining power, in low diurnal and seasonal range of temperature and about equal so far as quantity of clear sky is concerned. For such a large telescope as a 72-inch there could be no question of the marked astronomical advantages of such a location, and it was therefore decided to locate the telescope at Victoria. While the observatory should not be in the city itself it should not be too far away, not only on account of accessibility and facility in obtaining supplies, but also the advantageous conditions of good seeing, low diurnal range of temperature and small rainfall were confined to a relatively small area near Victoria. An isolated monadnock called locally Little Saanich Mountain but now named Observatory Hill, was selected. This hill is about 7 miles north of Victoria and has a main road and an interurban railway passing its base. It has an elevation of 730 feet, sufficient area around the summit for all necessary buildings and was by far the most suitable site available.

Construction

The Provincial Government had generously agreed to give \$10,000 for the purchase of a site and to build a road to the summit. This undertaking was fully met and the road, splendidly located and constructed and costing over \$25,000, was completed in the spring of 1915. Contracts for the construction of the telescope pier and the circular steel walls of the building were awarded to a local firm and this work was completed in 1916. The revolving dome with accessories for the operation of the telescope was made by the Warner & Swasey Co., the builders of the telescope mounting, and was completed and erected in 1916, thus making the building ready for the telescope.

The design of the mounting was very carefully gone into by the Warner & Swasey Co. in collaboration with the writer and was completed in the autumn of 1914. Construction

was at once begun and the mounting was completed and temporarily erected at Cleveland in May 1916. It was then shipped to Victoria and permanently erected in its building by November 1916.

The order for the large disc for the 72-inch mirror and for an auxiliary flat of 55 inches diameter for testing the 72-inch was given to the St. Gobain Glass Works of Paris by the Jno. A. Brashear Co. as soon as the contract was awarded. The 72-inch disc was cast and annealed by June 1914 and was fortunately shipped at once without waiting for the 55-inch disc. It left Antwerp only about a week before war was declared and it was only by this small margin that Canada now has a 72-inch telescope. Grinding and polishing were at once begun but the lack of the large flat and other difficulties delayed the completion and it was not until April 1918, about a year and a half after the completion of the mounting, that the figuring was finally completed and the telescope ready for work. Nevertheless, for an undertaking of such magnitude the work was completed in record time, four and a half years after the awarding of the contracts.

SECTION 2.—THE BUILDING AND DOME

The Observatory Building

The building for housing a large reflecting telescope requires to be of special design for the best results. It should not rise above the shade temperature during the day and should rapidly assume and follow the external temperature at night. Such materials as brick or stone are obviously not suitable and all recent telescope buildings are entirely of metallic construction in order to assume quickly the night temperature, and of double-walled, ventilated type to prevent overheating from the sun's rays. The building for the 72-inch telescope is entirely of steel construction, circular in form, 66 feet in external diameter and with vertical walls 32 feet high. A view from the south is given in the Frontispiece and from the north in Fig. 1, showing the city of Victoria and the straits of Juan de Fuca in the background. An external and internal



FIG. 1.—OBSERVATORY BUILDING FROM THE NORTH

covering of galvanized iron separated by about 16 inches allows free circulation of air from a peripheral opening at the base up through a similar double walled dome and out of louvres at the top. The ground floor of Terrazo is laid directly on the rock base and the observing floor 22 feet above this is formed of steel girders and checkered steel plate. In the centre of the ground floor rises the massive pier to support the telescope, of reinforced concrete and symmetrical tapering form. The pier is actually double, united below the observing floor by a massive reinforced arch and extending above the floor as two piers (see Fig. 2) one for each end of the polar axis. Temporary partitions on the ground floor provide a dark room, sleeping room, and temporary office quarters.

The Dome

This circular steel building is capped by a circular plate supported by massive girders on which is placed a curved railroad iron rail turned and adjusted perfectly level and circular. The hemispherical dome turns on this rail on 24 massive wheels mounted on roller bearings and is rotated by an electric motor mechanism operated by reversing switches on each side of the south pier. The framework of this dome, which is 66 feet in external diameter and about 38 feet high, the lower 5 feet being cylindrical, consists essentially of a circular base to which the bearing wheels are attached and two double, very deep and rigid main ribs, one of which can be seen in Fig. 3, 16 feet apart in the clear and extending parallel to each other entirely across the dome. These are united 6 feet beyond the zenith by a cross girder and this opening, which can be revolved to any azimuth and can be closed by double motor operated shutters, enables the telescope to observe at any part of the sky. Auxiliary circular ribs reaching from the base ring up to the main ribs all around the dome except at the shutter opening, form the support for the double steel covering of 12 inches separation. This ventilating space is united through suitable weather guards with the space between the building walls and forms the protection against overheating by the sun in the day time.

Dome Accessories

The shutter opening 16 feet wide and extending from the base of the dome to 6 feet beyond the zenith is closed by a double shutter also double walled and ventilated. Canvas screens mounted on tubes and operated by motor can be run up from the base of the shutter opening, this one being shown in Fig. 3, and down from the top so as to limit the opening to the width of the tube of the telescope. These screens are necessary when the wind is blowing to prevent shaking of the tube and consequent jumping of the star image. For enabling the observer to reach conveniently the upper end of the telescope tube in any position a counterweighted elevating platform, moved up and down the shutter opening by motor and drum with lifting cables is provided. This platform is 20 feet long and 4 feet wide with a wing at each end, extending inwards about 6 feet, on which the observer can stand and can move it and himself by a hand wheel up to and partly encircling the telescope tube. The platform and movable wings, which are well shown in Fig. 3, can be brought to any desired height by an operating switch at one side and can be reached by an auxiliary stairway from a small stationary platform attached to the base ring of the dome. This stationary platform is reached from the observing floor by a permanent stairway moving with the dome and extending to a foot from the floor. Platform wings and stairways are made safe for observers by guard and hand rails 30 inches high. This moving platform, an essential accessory for direct photography and other work at the principal focus of the telescope, meets, in a more convenient and satisfactory manner than any other previous device for the purpose, all the observing requirements for work at the upper end of the tube.

Mechanism for Silvering

In order to renew the silver coating on the upper surface of the mirror, which is necessary about three times a year, mechanism has to be provided for handling the mirror and its cell, the lower section of the telescope tube, with ease and safety. The mirror weighs over 2 tons and the cell 4 tons.



Fig. 2.—TELESCOPE IN AVERAGE OBSERVING POSITION

so 6 tons have to be removed from and replaced on the telescope tube. This is effected by means of the silvering car, which can be seen at the left of Fig. 2, a massive framework of structural steel rolling on four flanged wheels on flush tracks in the observing floor. With the tube turned to a vertical position, the car is rolled from its normal position at the east side of the dome directly under the tube and a motor-operated screw-jack surmounted by a triangular rocking arm can be brought up against the bottom of the cell. On removing the attaching bolts, cell and mirror can be lowered and rolled on the car to the east out of the way. The removal of 6 tons from one side throws the telescope out of balance and so the outboard end of the declination axis is supported by a counterweighted strut run up through the floor and the upper end of the tube tied to rings at the top of the dome. With a band of paraffined paper tied around the edge of the mirror and a plug in the central hole, the silvering solution can be poured on and evenly flowed over the surface by rocking on a steel ball at the top of the jack-screw. When the silvering is complete, cell and mirror are replaced in the reverse order and the car rolled back out of the way. The operation takes about a day and is performed with perfect safety and ease.

SECTION 3.—MECHANICAL PARTS OF TELESCOPE

Introduction

It is useful, before describing the mechanical parts or mounting of the telescope, to explain the difference between the two kinds of telescope, refracting and reflecting, employed in astronomical work. The refracting telescope is the most familiar type as the ordinary spyglass or draw-tube telescope and the field or opera glass are all refracting telescopes. The refracting telescope is so called because the light from the distant object is refracted through a lens at the outer end of the tube and forms an image of the object at the inner end, just as a camera forms an image on the ground glass or film, and this image is viewed and magnified by the eyepiece or ocular. The reflecting telescope on the other hand has the

upper or outer end of the tube open and the light from the distant object is reflected (hence the name) from a concave mirror at the lower end of the tube, forming the image of the object at the top, where it can be viewed and magnified by the ocular as in the refractor.

Each type of telescope has its astronomical advantages and disadvantages. The refractor is better suited for visual observations such as the measurement of double stars and the study of planetary detail and is less affected by temperature changes than the reflector. On the other hand the reflector, on account of its perfect achromatism, is the instrument par excellence for photographic observations, and, as more than three-fourths of modern astronomical work is photographic, it appears to be superseding the refractor. This advantage is increased by the fact that the refractor has apparently reached the useful limit in size and that it costs at least three times as much as a reflector of the same aperture. Although each type of telescope has its characteristic type of mounting for astronomical purposes, the principles are the same for each and can probably be most easily followed by describing the essential parts of the mounting of the 72-inch telescope.

The Telescope Tube

The tube performs the important function of carrying in relatively invariable position and adjustment the optical parts of the telescope. The tube of the 72-inch telescope is 31 feet long, 7 feet 4 inches outer diameter and weighs 15 tons. Its form and construction are well shown in Figs. 2 and 3. It consists of the main or central section A, Fig., 2 the lower section B which carries the main mirror and the skeleton section C which carries the secondary mirrors. The central section is a cylindrical steel casting heavily ribbed on the inside about 6 feet high and weighs 7 tons. The lower section is securely bolted to it through the flanges shown and with the mirror and its supporting mechanism weighs about 6 tons. The upper skeleton section is built up of structural steel, 3 inch I beams, firmly braced and rivetted together in the manner shown in the figures. A

special feature of this skeleton tube, making it more rigid than any previous design, consists of the diagonal tension rods in each rectangular compartment screwed up each to a tension of about 2,000 pounds, so that the whole tube is under tension in every position. This stiffness is essential for the proper performance of the optical parts, as the principal and secondary mirrors at bottom and top of tube respectively should occupy the same relative positions in whatever direction the tube is pointed.

The Declination Axis

The telescope tube is firmly screwed at right angles to the flanged end of a massive shaft 16 inches in diameter, called the declination axis, extending through the cubical section D of the polar axis NDS, Fig. 2, through the declination sleeve E into the housing F. This declination axis is rotated, carrying the tube with it, on ball bearings in D and F, this rotation being effected by an electric motor with reduction mechanism, gearing into a large spur gear attached to the end of the declination axis, the whole being concealed within the declination housing F. Hence the tube can be turned at the rate of 45 degrees to the minute to any required position up or down, north or south. The position in the sky, the declination, corresponding to latitude on the earth, is read on a large circle graduated into degrees within F and subdivided into 5 minute intervals on the small auxiliary circle H.

The Polar Axis

As positions north or south are given by turning the tube on the declination axis, so positions east or west are given by rotation on the polar axis, so called because it points to the pole of the heavens and is exactly parallel to the axis of the earth. The Polar axis NDS Fig. 2, which is 21 feet long and weighs 9.5 tons, is built up of three steel castings, a central cubical section D and two conical end sections, all securely bolted together and turning in ball bearings on its ends. The upper, north, bearing is carried in an adjustable pillow block, by which the final parallelism with the earth's axis is obtained,

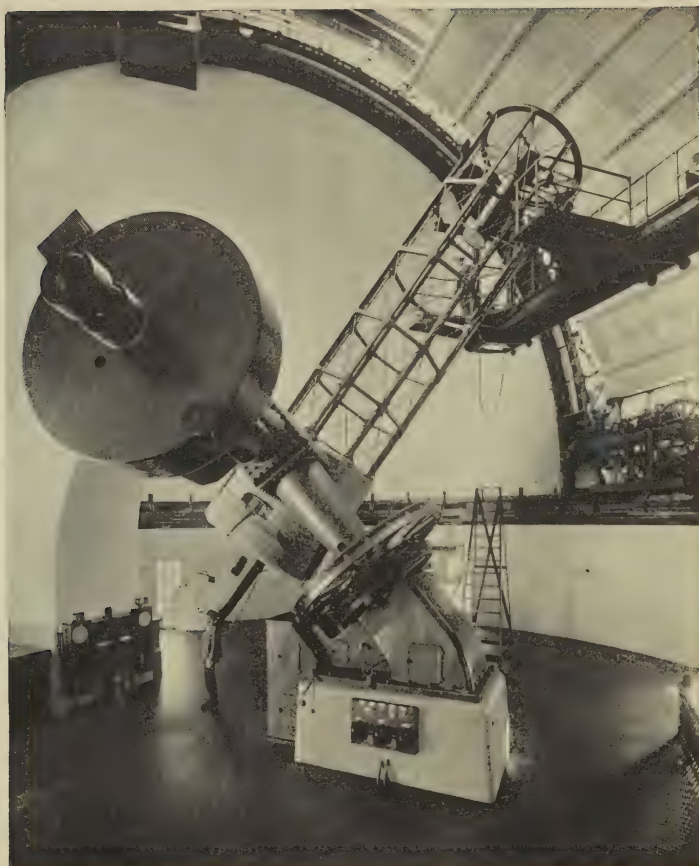


Fig. 3.—TELESCOPE FROM THE WEST

bolted on the curved cement pier shown at the left or north in Figs. 2 and 3. The lower, south, bearing is carried in a massive cast iron pedestal bolted to the south cement pier. The polar axis is rotated on these bearings, also at the rate of 45 degrees per minute, carrying the declination axis and tube with it to any position east or west in the sky by an electric motor and reduction gearing concealed within the south pedestal. The position east or west in the sky, the right ascension as it is called corresponding to longitude on the earth, is read by means of a graduated circle shown above G, Fig. 2, which is divided into 24 hours and each hour into single minutes. While longitudes on the earth are occasionally expressed as so many hours and minutes east or west of Greenwich, right ascensions in the sky are almost invariably given in hours and minutes rather than degrees.

The Driving Clock

It is evident, by rotation of the telescope on the declination and polar axes by means of the quick-motion motors, that the tube can be pointed in any direction in the sky, towards any star. But owing to the rotation of the earth on its axis from west to east, which is the cause of the apparent motion of sun, moon and stars from east to west, the telescope will be quickly carried eastward of the star which will only remain for an instant in the field.

The mechanism by which the rotation of the earth is compensated for is called the driving clock and is contained in the case L, Fig. 2, at the north side of the south pier. In the lower half of the case a governor similar to the governor of a steam engine is driven once per second by a train of gears in the upper section actuated by a weight of 300 pounds below the floor. If the speed of the governor tends to increase the balls raise by centrifugal force and bring increased friction to bear thus reducing the speed to normal while if the speed tends to decrease, the balls drop and reduced friction quickly allows it to accelerate to normal speed. A shaft with a coarse screw thread on it, called technically a "worm" and situated at the top of the case, is driven by intermediate gearing from

the governor at the rate of one revolution every two minutes. The thread on this shaft engages into teeth cut in the worm wheel G, Fig. 2, which is 9 feet in diameter. As there are 720 teeth very accurately spaced in this worm wheel, it is driven around by the worm in $2 \times 720 = 1,440$ minutes, 24 hours, the same rate as the earth. This worm wheel, normally loose on the polar axis on which it turns on ball bearings, allowing the axis to be moved freely to any position, can be rigidly clamped to it by pressing a button. When this is done, it will evidently turn the polar axis and hence the tube at the same rate as the earth but in the opposite direction, on an axis parallel to the axis of the earth, thus exactly compensating for the rotation of the earth. Hence any star at which the telescope is pointed will automatically remain central in the field. Owing to the great magnification all this mechanism requires the highest grade of workmanship, else there will be wandering of the image, a most annoying and troublesome defect. Few telescopes are entirely free from periodic error and that the 72-inch drives so regularly and smoothly is a great advantage and evidence of the perfection of workmanship throughout.

Electric Motions

It has already been described how the telescope can be moved by motors north or south and east or west at the rate of 45 degrees per minute. These motors are operated from small switchboards on each side of the south pier, the one at the west being seen in Figs. 2 and 3. The left-hand reversing switch moves the telescope east or west, the centre switch north or south and the right-hand switch revolves the dome east or west. In addition to these quick motions of the telescope for rapidly bringing it to the approximate position, much finer and slower motions are required for bringing the image exactly central and for guiding. These slow motions are also operated by electric motors actuated by two small aluminium switchboards attached by flexible cables to the top and bottom of the tube. These switchboards can be carried in the hands of the observer or rested on the observing

ladder. Pressure on suitable buttons moves the telescope north or south, east or west at either one of two different speeds, a speed of one revolution in 36 hours for centering the image and a speed of one revolution in 30 days for guiding, correcting for slight irregularities due to air disturbance or other causes. Although these speeds may seem excessively slow, the motion of the image even with the monthly rate is at once evident on pressing the button and faster speeds would make accurate guiding difficult. In addition to the two quick and two slow motion motors there are two clamping motors and one for automatically rewinding the clock weight, seven in all. These with the three motors operating the dome are all continuous current motors which can be started and reversed more readily and have greater initial torque than alternating motors. Each motor is supplied with an automatic control, so that all that is necessary is to throw the switch or press the button to start or reverse. Current is supplied by a motor generator set on the ground floor.

Method of Operation

A description of the method of setting upon the required star, when, for example, photographing the spectra of the stars, will help to make the operation of the telescope more clearly understood. It is easily possible to pull the telescope around by hand to the required star identified by eye among the constellations. Although the moving parts of the telescope weigh nearly 45 tons, so perfect are the ball bearings in which it turns that a weight of 3 pounds at the upper end of the tube is sufficient to set it in motion. However the settings can be much more quickly and certainly made by turning the telescope to the right ascension and declination of the star by the electrical motions. A programme of the stars to be observed with their right ascensions and declinations is prepared beforehand. The observing assistant stands beside the small switchboard on the south pier and rapidly moves the telescope east or west and north or south until the indexes on the graduated circles point to the tabulated positions, while the dome can be turned to the required position at the same time.

by means of the third operating switch. By pressing two buttons the telescope is then firmly clamped and the driving clock starts the telescope automatically following the star. In the meantime the observer has inserted the plate holder in the spectrograph and drawn the slide and by means of the aluminium switchboard brings the star, which is generally near the centre, exactly to the centre of the finder, when it will be visible on the slit of the spectrograph through a guiding eyepiece and can quickly be brought central and the exposure commenced. The time required from the end of one exposure to the beginning of the next, unless the stars are far apart in the sky, does not generally exceed two minutes, a shorter time than usually required for even quite small telescopes. This rapid operation is due to special care in design and construction and markedly increases the efficiency and capacity of the instrument.

Special Features of the Mounting

The mounting of the 72-inch telescope has several new features not hitherto used and sets a new standard for convenience and accuracy of operation. The observatory is much indebted to the Warner & Swasey Co., who have made most of the large mountings in America, for the spirit in which they undertook and carried through this work. Their sole object was to produce the best possible mounting regardless of cost and no suggestion of the writer looking to improvement was refused. To Mr. Swasey, the president, are due many of the original features of the mounting and the beauty and harmony of the design, while Mr. Burrell, the works manager, is responsible for the simplification of the mechanism and the beautiful co-ordination of the details. No greater testimony to the perfection of design and construction can be given than to say that after five years use there is no feature the director would wish changed, and no single defect of construction has been revealed.

It may be of interest to note the principal improvements in this mounting.

1. All parts of the sky can be readily reached. This is not possible with all types of reflecting telescopes.

2. The elimination of cylindrical bearings with cumbrous friction-relieving devices, formerly considered necessary for maintaining collimation and adjustment on declination and polar axes, and the use of ball bearings for both friction-relieving and collimating purposes has resulted in remarkable ease of movement of the telescope.

3. Freedom from periodic or other errors in driving and smoothness and freedom from "backlash" in slow motions.

4. Ease, speed and accuracy with which settings can be made due to careful design and original features in setting motors and setting circles.

5. Great stiffness of tube and improvements in method of attaching and changing secondary mirrors.

6. Beauty and harmony of design and appearance.

SECTION 4.—OPTICAL PARTS AND SPECTROGRAPHS

The Principal Mirror

The great mirror is composed of hard plate glass cast in one piece and after annealing, ground and polished to the correct shape. As received from the St. Gobain Co., the disc was 73.5 inches diameter, over 13 inches thick with a central hole about 6 inches diameter and weighed nearly 5,000 pounds. It was first of all ground truly circular to a diameter of 73 inches and flat on both sides to a thickness of slightly over 12 inches, while the central hole was enlarged to 10 inches. When the back was polished approximately flat, the disc was seen to be a beautiful specimen of the glass makers art, homogeneous and almost entirely free from bubbles or other defects.

It was now ready for the second stage of the operation the grinding of the correct shape for the upper reflecting surface. In order to bring the light of a star to an accurate focus this surface must be a paraboloid of revolution, the same kind of curve given to the reflectors of search lights or automobile headlights. The curve for this reflector of 30 feet focus is very nearly a section of a sphere of 60 feet radius, within



Fig. 4.—PHOTOGRAPH OF RING NEBULA IN LYRA
(Enlarged 8 diameters)

one-thousandth of an inch, and consequently would nearly fit a huge globe 120 feet in diameter. The upper surface of the disc was fine ground and polished to this spherical surface and was then ready for the final stage, the "figuring" a continuation of the polishing process until the centre is deepened about a thousandth of an inch and the surface becomes accurately paraboloidal. This "figuring," an exceedingly delicate and difficult process especially over such a large surface as the 72-inch, with the added difficulty of a central hole, occupied about two years and was not completed until nearly a year and a half after the mounting was ready. When it is remembered, however, that the surface nowhere deviates from the true theoretical form more than one four-hundred-thousandth of an inch and that if one part is accidentally polished too deep, the whole surface has again to be brought down to this level, the exceeding delicacy of the operation is evident and the time taken not excessive.

Accurate quantitative tests showed that the final figure is of the highest order of accuracy and this is further clearly shown by the practical test of direct photographs at the principal focus. Figure 4, a six fold enlargement of a photograph at the principal focus, of the Ring Nebula in Lyra shows how sharp and small are the star images. Actual measurement on the original negative gives a minimum diameter of two one-thousandths of an inch equivalent to only a second of arc at the focus. As the images are enlarged considerably by unsteadiness of the air and errors in guiding the star light reflected from the whole surface of the mirror is collected into a little disc less than a thousandth of an inch in diameter indicating the extraordinary accuracy of the reflecting surface. Mr. J. B. McDowell, head of the firm since Dr. Brashear's death, and Mr. Fred Hegemann, his chief optician, are to be highly congratulated on the perfection of figure obtained under specially difficult circumstances. Further the fine rendering of the detail in the ring and the strength of the two bands in the interior indicate not only perfect figure but exceptionally high polish.

Mounting of Mirror

This mirror, to maintain its accuracy, not only requires careful mounting in its cell but also protection against temperature changes. Even though 12 inches thick it would bend under its own weight of 4,300 lbs. sufficiently to affect the figure and consequently it is supported in the cell by a specially counterweighted lever system so that it is equably supported at twelve points and there is no tendency to bend. A similar lever support system around the edge prevents distortion due to constraint when it is tipped from the horizontal position at different positions of the tube. Temperature changes can produce much greater distortion than flexure but Victoria has the advantage of very low diurnal range and the temperature change around the mirror is made very small by a lagging of cotton felt about 2 inches thick all round the sides of the closed section of the tube, laced on with a duck cover (compare Fig. 3 with Fig. 2) and an equal thickness below and around the edge of the mirror. By this lagging the temperature rise in the day-time is only about half a degree while the dome temperature increases five degrees, hence the figure of the mirror remains good whatever the temperature changes outside.

The Principal Focus

As already indicated, the principal mirror when used alone forms an image of the star 30 feet above, at the centre of the upper end of the tube, and an eyepiece could be placed there for visual work or a photographic plate for direct photographs of nebulae, etc. However, it is generally more convenient to use a flat mirror at 45° forming the image at the side of the tube for photographs and so the telescope is only used in this form with a small spectrograph for the ultra-violet region of star spectra. The course of the parallel beam of light from the star to its image on the slit of the spectrograph is graphically shown in Fig. 5 A and also its passage through the slit prisms and lenses of the spectrograph. The position of the star image on the slit of the spectrograph can be observed by a guiding telescope extending

to the edge of the tube and can be kept central by the portable aluminium switchboard already described. The elevating platform is of course used in work in this position.

The Newtonian Arrangement

For direct photography or visual observations at the focus of the 72-inch mirror, the reflected cone of star light from the mirror B, Fig. 5, is intercepted by a plane mirror also silvered on the front surface, 19.5 inches diameter and 3.25 inches thick placed at 45° . This form of reflecting telescope was first used by Newton, hence the name. The focus is then formed, as shown, at the side of the tube, and if a plate is placed there and accurately guided by small eyepieces with cross wires, photographs of any desired small region in the sky can be obtained, Fig. 4 being made in this position, or visual observations may be made. The oculars can easily be reached from the observing platform for any position of the telescope.

The Cassegrain Arrangement

The most generally useful arrangement of the 72-inch telescope is, however, the Cassegrain form, so called from the French astronomer who first used it. About 7 feet below the focus, the conical reflected pencil from the 72-inch mirror is intercepted by a convex mirror of the same size as the Newtonian and of about 10 feet focal length as seen in C, Fig. 5, and also shown in Fig. 2 and 3. This mirror turns the light downward and, after passing through the central hole, forms the image of the star about two feet below the mirror surface on the slit of the spectrograph or on a visual attachment as shown. The significant property of this combination is that the focal length is increased from 30 to 108 feet without changing the tube length in a somewhat similar manner to the action of a telephoto lens. It has the same size of image and magnifying power as a refractor with a tube 108 feet long and has the decided advantage of a much shorter tube and smaller dome. Observations with this arrangement are made at the lower end of the tube from the observing floor and

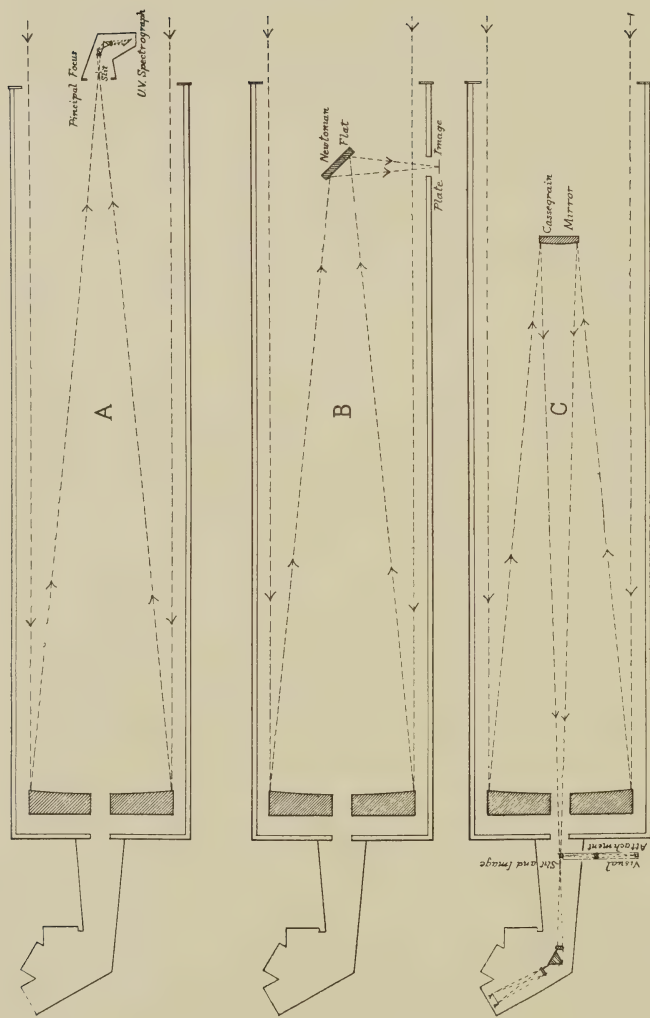


Fig. 5.—COURSE OF LIGHT IN TELESCOPE FROM STAR TO FOCUS

with much greater ease and convenience than at the upper end. Changes from the Cassegrain to the Newtonian or Principal Focus arrangements are readily effected by a device due to the genius of Mr. Swasey whereby only the mirrors and attaching tubes require to be handled, instead of the whole upper end of the tube as in previous reflectors.

Accessory Optical Parts

A full set of eyepieces giving magnifying powers from 120 to 5,000 diameters and a complete double-slide plate holder with guiding eyepieces for direct photography at the Newtonian focus are provided. In addition there is a visual attachment shown in diagram C, Fig. 5, which enables the telescope to be used visually at the Cassegrain focus without removing the spectrograph. There are three finders attached to the telescope tube for picking up and centering the stars. Two of 4 inch aperture and 5 feet focus, of power about 50, one north, one south on the tube, and a long focus tubeless finder with a lens of 7 inch aperture and 30 feet focus at the top of the telescope tube and an ocular of power 200 at the bottom.

The Spectrographs

Most of the astronomical work with the 72-inch telescope is spectroscopic, photographing the spectra of the stars, and so a description of the principles and operation of spectrographs is desirable. Stellar spectrographs have evolved into certain definite forms and the two spectrographs for the 72-inch telescope are examples of the most recent types. In essence a spectrograph consists of a narrow slit, one or two-thousandths of an inch wide, on which the star light is focussed. That passing through the slit falls on the collimator lens which makes it parallel and then on a prism or prisms, triangular shaped pieces of glass which change the direction of the light and decompose it, breaking it up into its constituent rainbow colours. The spectrum, as it is called, is focussed by a camera lens on a photographic plate or can be viewed by a small telescope if desired. The course of the star light

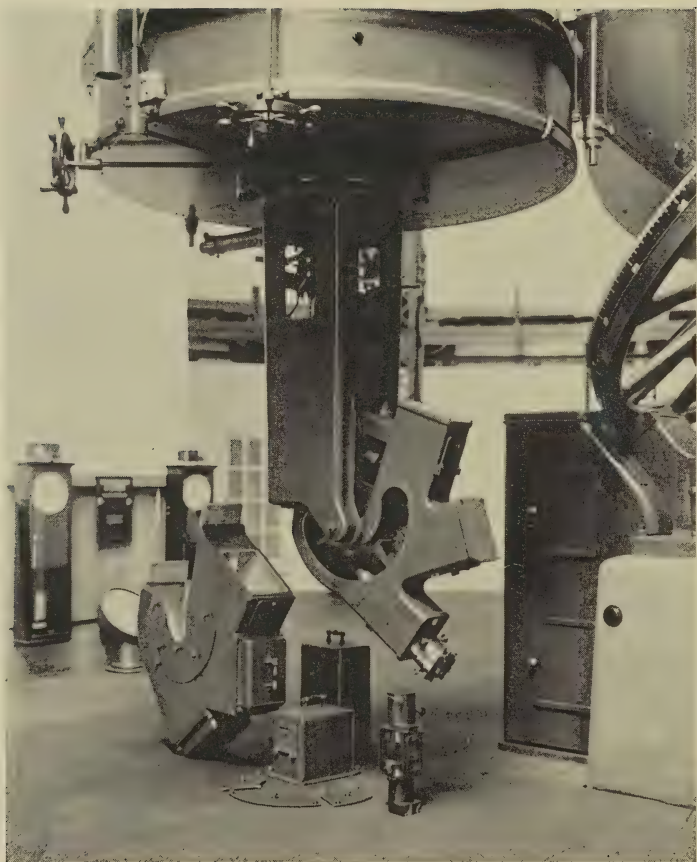


Fig. 6.— STELLAR SPECTROGRAPH ARRANGED FOR USE WITH ONE PRISM
(TEMPERATURE CASE REMOVED)

from the slit through collimator, prism and camera lens to the plate is shown in C, Fig. 5, while a view of the Cassegrain spectrograph showing the interior mechanism and accessories is given in Fig. 6. The part of the spectrum photographed is usually only the blue and violet region to which the ordinary plate is most sensitive, and obviously no colours appear on the negative but only a narrow dark strip which is crossed by light or dark lines. It is from the number and position of these lines that we obtain such a remarkable amount of information about the physical and chemical constitution, the temperature, motion and distance of the stars. The length of the star spectrum photographed with one prism is about one and a third inches, twice and three times that with two and three prisms. Its width is about one-hundredth of an inch and in order to make it this wide the star image has to be moved back and forward along the slit. The length of spectrum with the ultra-violet spectrograph, which only differs from the other in the prisms and lenses allowing the spectrum below the violet to pass, is about one inch. A photograph of the spectrum of iron or brass is made beside the star spectrum to serve as a standard to determine the positions of the star lines.

Method of Use

Every terrestrial element gives groups of lines in certain positions in the spectrum and if we find similar groups in the star spectrum we are sure this element is present in the star. Further if we find these lines are displaced to red or violet of their normal position we know that the star is receding from or approaching to us. With the one-prism spectrograph a speed of one mile per second means a displacement of the lines of one thirty-thousandth of an inch. Thus if the lines are shifted to the violet by a thousandth of an inch, the star is approaching the earth with a speed of 30 miles a second. These displacements are accurately measured by a microscope and the measurement of the radial velocities of the stars is one of the main researches of this observatory. Obviously with such small displacements to be measured the greatest

care must be taken to avoid all sources of error. The spectrograph must be exceptionally rigid to avoid differential bending as it moves with the telescope. As change of temperature can produce spurious shifts of the lines, the temperature must be kept as constant as possible, this being effected here by a very accurate electrical thermostatic device called the Calendar Recorder which maintains the temperature constant to one-hundredth of a degree. The optical parts must be of the highest quality to give perfect definition to the spectrum lines and many other precautions must be taken if accurate work is desired. The spectrographs of the 72-inch telescope have unequalled defining power and are the last word in convenience of manipulation and accuracy of work.

Owing to the faintness of the star light and to its being spread out into a spectrum a considerable time is required to photograph the spectrum of a star, about 20 minutes for the sixth magnitude, the limit of visibility to the unaided eye, when photographed with one prism, while three prisms will take nearly five times as long. Hence the necessity and use of large telescopes is not to get high magnifying power but to collect sufficient light from the fainter stars to enable their spectra to be photographed or other observations made.

SECTION 5.—THE WORK OF THE TELESCOPE

Prevalent Misconceptions

The general idea of an astronomer's work, as gathered from the questions and remarks of visitors, is that he sits at the eyepiece of the telescope sweeping the heavens in a search for new planets, comets or stars. The absolute futility of such a use of the telescope is evident when it is realized that the main field of the 72-inch covers only about one hundred-millionth of the sky and if only five seconds was required to examine each field it would take more than a lifetime to go over the whole sky once. A second misconception is the idea that large telescopes are used for visual observations of the planets with special reference to their habitability. No work is being attempted at this or other large observatories

on planetary detail for which about an 18-inch refractor gives the best results and such a large telescope as the 72-inch is quite unsuited. All scientific observations with the 72-inch are made photographically and it is only arranged for visual use on Saturday evenings when for two hours visitors are allowed to observe the heavenly bodies. A third misconception is that the astronomer only works at night. However true this idea may have been in the days of visual observations when the measurements were made at the eyepiece, there is certainly now, when photography is so generally applied, more day than night work in astronomy. Besides the advantages of permanency, accuracy of measurement and power of recording objects beyond the range of the keenest eyesight, the photographic method has the further great advantage that an hour's exposure may give sufficient material for several days' measurement and discussion.

Spectroscopic Work

As already indicated most of the work with the 72-inch telescope is spectroscopic, but as also indicated modern spectroscopic investigations cover so wide a range of research that the actual work of the observatory is very varied. By aid of suitable spectrographs attached to a large telescope we can measure the speed of the stars towards or from us, their radial velocity as it is termed. We can discover double stars too close ever to be seen double in any telescope and we can determine the manner in which they revolve around one another and their distance apart and mass. From the spectra of the stars we can determine their absolute brightness as compared with the sun and their parallax or distance. The chemical elements present in the outer atmospheres of the stars can be determined and the pressure in these atmospheres. The measurement of temperatures and other physical conditions in the stars by means of the spectroscope is now an accomplished fact and one of the most recent developments of the spectroscopic work here has been to provide evidence of the truth of a theory of atomic structure and to show that the atomic constants in the enormous furnaces of the stars are

the same as on the earth. Such a catalogue of information, obtained from an investigation of the mere quality of the light from stars so faint as to be quite invisible to the unaided eye and so distant that it may take thousands of years to travel to us, is sufficiently comprehensive to be treated in more detail.

Radial Velocities

When the 72-inch telescope was in course of design and construction, one of the greatest needs in astronomical work was increased data in regard to the radial velocities of the stars. Although the telescope was so designed as to be suitable for all kinds of observational work, special attention was devoted to the spectroscopic end. After consultation with the most prominent astronomers an observing programme of about 800 stars whose "proper" or cross motions across the sky were accurately known but whose radial velocities had not been determined, was prepared and spectroscopic observations of the stars on this programme were commenced as soon as the telescope was completed in May 1918. After slightly over three years' work, observation and measurement were completed and Vol. II, No. 1 of the observatory publications, "The Radial Velocities of 594 Stars," was published early in 1922. As hitherto the radial velocities of only about 2,000 stars had been obtained, this work was a considerable addition to existing data about the motions of the stars and will be of great use in extending our knowledge of the structure and motions of the universe. A second programme of 1,500 stars has been prepared but owing to other intervening observational work, not much has yet been done on this new programme.

One of the auxiliary programmes undertaken and nearly completed since the first programme is the determination of the radial velocities of a very interesting but limited class of stars, the highest temperature stars known, the O-type stars. The radial velocities and other interesting data about 50 of these stars have been completed.

Spectroscopic Double Stars

In the measurement of the radial velocity of the 800 stars on the first programme it was found that in about 180 stars successive plates did not give constant velocities, the stars at one time approaching at another receding from us. This phenomenon is practically certain proof that we are measuring the velocity of a star revolving around an invisible companion and such stars are generally called spectroscopic binaries to distinguish them from visual binaries which can be seen double in the telescope. Over 200 spectroscopic binaries have been discovered at this observatory as compared with about 700 discovered elsewhere, again a considerable addition. In about 20 of these binaries, observations were continued until the period of revolution, the form of the orbit, the separation of the two stars and in some cases, their masses were determined. In a particular class of spectroscopic binaries, the eclipsing variables, which allow from the combination of spectroscopic and photometric measurements the absolute dimensions to be obtained, we were able to determine the separation of the two stars, their diameters, densities, masses and brightnesses and the probable distances. Such complete information has been obtained here about seven systems, while only seven other systems have been determined elsewhere.

Absolute Magnitude and Distance

A new application of spectroscopic methods is to the determination of the total brightness of the stars as compared with the sun and their distance or "spectroscopic parallax" as it is called. This depends not on the positions but on the relative intensity or strength of the lines in the spectra of the stars and has only been developed in the last three or four years. The absolute magnitude and spectroscopic parallax of about 800 stars is now nearly completed and will soon be published while as a side line the radial velocities of 125 more stars have been determined.

Physical Conditions in the Stars

The spectrographs have also been used by one member of the staff in the determination of the physical and chemical conditions in stellar atmospheres, a new and difficult problem but one which promises not only very valuable additions to our knowledge of the constitution of the stars but may also lead to economic applications of the greatest importance. A new method depending upon the use of a wedge of dark glass has been applied to determining the distribution of energy in the different parts of the spectrum of the stars and to measuring their temperatures, while an application of the same methods to individual lines may lead to a great increase in our knowledge of conditions in the stars. A special investigation of three of the high temperature O-type stars referred to above has proved the existence in the spectra of these stars of lines predicted as present from purely theoretical conditions but never previously identified and has thus remarkably verified a theory of the structure of the atom. The measurement of the wave lengths of these hitherto unknown lines has led to an important independent determination of the fundamental constants of atomic structure and the dimensions of the atom and has shown that these constants and dimensions are the same in the tremendous furnaces of the stars as in our terrestrial laboratories, a verification of the homogeneity of matter and the uniformity of physical laws throughout the universe. Further interesting results from this investigation are the application of a new theory of ionization with the probable relative abundance of the elements to an independent determination of the temperature of these stars.

Other Investigations

Direct photographs have been made of some nebulae and clusters but this work is not being definitely followed at present. Investigations into the phenomena accompanying some short period binaries have been made and into the behaviour of the two strong calcium lines H and K in the spectra of the high temperature stars from which interesting and valuable results are expected. Since the observatory

commenced work two bright novae or new stars have appeared, which have been fully observed spectroscopically here and the results discussed. The plates of the nova in Aquila have been loaned to the observatory at the University of Cambridge, England, for fuller discussion and analysis.

Value of Astronomical Work

This brief sketch of the work of the observatory naturally leads to the question frequently asked of astronomers:—What use is the work done at observatories and what practical value can a knowledge of the stars have in everyday life? While astronomy has obvious practical applications to navigation and surveying yet nine-tenths of modern astronomical research is devoted to the more or less abstract question of the constitution and motion of the stars and the structure of the universe. Indeed most physical and chemical as well as astronomical research is undertaken for the purpose of increasing our knowledge and of investigating the secrets and laws of nature and has generally no direct practical economic application. But it is now generally recognized by the layman as well as the scientist that without abstract there can be no applied science and that all the great economic and industrial applications of science have had to be preceded by the abstract and apparently non-practical investigations of pure science. The Great War perhaps made more evident than ever before the absolute dependence of applied science upon the unselfish and abstract work of pure science.

Economic Value

In view of past experience in science it would hence be a rash prediction to assert that the investigation of the conditions in distant stars can have no practical application upon earth. It may be of interest to point out one possible application of astrophysical research.

It is generally agreed that one of the most important economic problems of the not far distant future will be the provision of sources of energy to replace our rapidly depleting supplies of coal and oil. It appears now that the most prob-

able solution of this problem will consist in the development of some method for utilizing the inexhaustible stores of energy contained in the atoms of matter. Modern research on conditions in the stars has made it practically certain that the enormous supply of energy, which has been radiated into space for aeons of time from these bodies, can only be maintained undiminished by the energy released by the transformation of atoms in the interior of the stars, where conditions of temperature and pressure prevail at present unattainable in terrestrial laboratories. The most hopeful line of attack upon this tremendously important economic problem hence seems to lie in the systematic astrophysical investigation of conditions in the stars supplemented by physical and chemical researches on the structure of the atom.

Ethical Value

While astronomers and scientific men generally fully realize the value of the practical applications of science, their main purpose is the search for truth and the extension of our knowledge of nature. While it is possible that investigation of the stars may have immense economic value, it is certain that it has tremendous ethical value giving us a clearer knowledge of the laws of nature and of our relations to the wonders of creation. Astronomy is the oldest and in many respects the most important of the sciences and its study, through the ages has been one of the most elevating influences on human character. Poincaré has well said that if the earth had been so continuously covered with clouds that the heavenly bodies could not be seen, mankind would still be in a primitive state and under the domain of superstition. The main superiority of modern over ancient civilization does not consist in the greater abundance of the necessities and luxuries of life, although this is undoubtedly due primarily to scientific research, but to the elevating influences of the truer conceptions of nature made possible by the abstract study of astronomy and other sciences.

It has been truly said that the degree of civilization of a country may be judged by the support it gives to the study

of astronomy. By the establishment and maintenance of the Dominion Observatory at Ottawa and of the Dominion Astrophysical Observatory at Victoria with the second largest telescope in the world, Canada has a just claim on this criterion to the favourable estimation of the scientific world.

VICTORIA, B.C.,

May, 1923.

